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Spin Tunneling Random Access Memory (STram)

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Abstract—**A storage mechanism in ferromagnetic-insulator-ferromagnetic spin-polarized tunneling junctions has been found by us. Based on this mechanism, we designed and fabricated a 2×2 bit Spin Tunneling Random Access Memory (STram). These junctions provide an excellent means of storing a binary data in the hard components, and sensing its remanent state by switching the soft component in such a way that the magnetic state of the hard component remains unaltered.**

I. Introduction

Spin tunneling effects have been observed in various ferromagnetic-insulator-ferromagnetic spin-polarized system [1]–[3]. Results obtained on these current-perpendicular-to-plane (CPP) giant magnetoresistance (GMR) effect show a low-field magnetoresistance change ratio as high as 32% [3], superior to conventional current-in-plane (CIP) GMR effect. From a fundamental point of view, the CIP configuration suffers from several drawbacks, the CIP magnetoresistance is diminished by shunting and channeling. In particular, uncoupled multilayers or sandwiches with thick spacer layers suffer from this problem, whereas the switching field in such system is usually small. Moreover, diffusive surface scattering reduces the MR for sandwiches and thin multilayers. Finally, fundamental parameters of the effect, such as the relative contributions of interface and bulk spin-dependent scatterings, are difficult to obtain using the CIP geometry [4]. Measuring with the CPP solves most of these problems, mainly because the electrons cross all magnetic layers, but a practical difficulty is encountered: the perpendicular resistance of ultrathin multilayers is too small to be measured by ordinary techniques. A good method to enhance the perpendicular resistance is introduction of tunneling barrier to GMR devices, as mentioned above [1]–[3]. Experimental results show that a relatively large resistance (from a few to tens of ohms) between two magnetic electrodes through the thin Al_2O_3 insulator can be obtained. Therefore, a microstructured spin tunneling junction has a potential application for a novel magnetic sensor with high spatial resolution [5] or for a high bit density solid state magnetic memory. The practical signal level can be expected from the relatively large tunneling resistance. This paper reports on a design, fabrication and test for a 2×2 bit Spin Tunneling Random Access Memory (STram).

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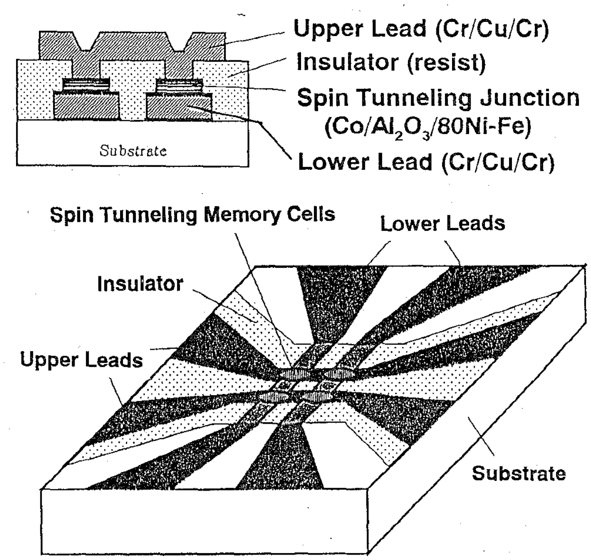


Fig. 1. Schematic diagram of the 2×2 bit STram.

II. Microfabrications

A 2×2 bit STram was fabricated using optical lithography and ion etching techniques. A brief outline of the fabrication method is given as follows. First, Cr (10 nm)/Cu (1000 nm)/Cr (30 nm) and Co (100 nm)/Al_2O_3 (8 nm)/80NiFe (100 nm) were sputtered onto the glass substrate whose size is 6×6 mm^2. The spin tunneling junction Co/Al_2O_3/80NiFe was prepared by RF sputtering with argon in a background vacuum of 2×10^{-7} Torr. The intermediate Al_2O_3 was formed by oxidizing Al film in air at room temperature for 24–30 hours after Co/Al deposition. After pumping down again, NiFe was deposited. Uniaxial anisotropy in ferromagnetic films, important both for memory storage and for the way that a bit is selected, was induced by a magnetic field of 15.5 Oe applied during sputtering. Consequently, the lower leads and spin tunneling junctions (cylinders with the radius of 50 μm) are formed by ion-etching, respectively. Then the sample was covered with a 1 μm AZ1350 pho-

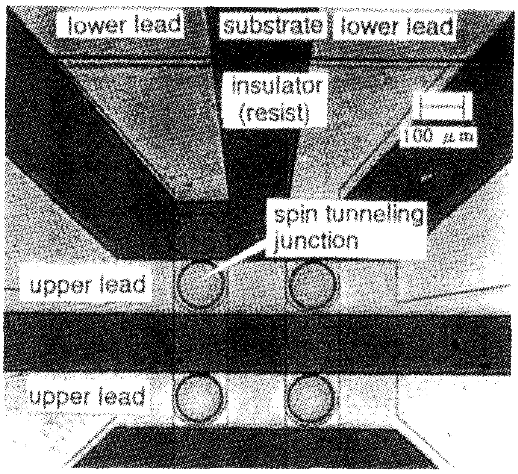
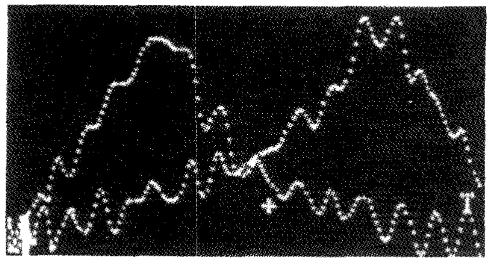


Fig. 2. Microscopy picture of the 2×2 bit STram.

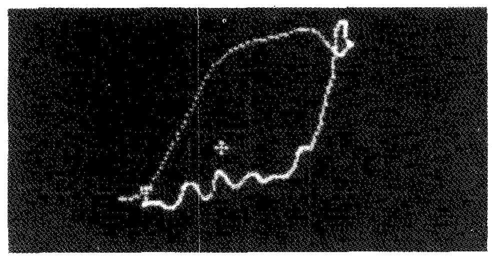
toresist by spin-coating, which serves as an insulator. Contact holes were etched in the resist, followed by a 300°C × 2 hour hard baking curement. After removing the contaminants and the surface oxidation layer formed on the NiFe surface by 3 minute counter-sputtering, Cr/Cu/Cr was sputtered onto the resist and patterned into the upper leads, orthogonal to the down leads. Finally, a 2×2 bit STram, illustrated in Fig. 1 and Fig. 2, was completed. In general, a practical difficulty with current-perpendicular-to-plane structures that the perpendicular resistance is too small to be measured by ordinary techniques can be solved by our design. A tunneling junction resistance as high as tens of ohms was achieved, attributing to the microsized cross section because the tunneling probability of electrons is proportional to the cross section. Microsized cross section also results in the reduction of the number of the metallic pin-holes in the intermediate Al_2O_3. We think this is another important reason of high junction resistance.

III. Storage Mechanism

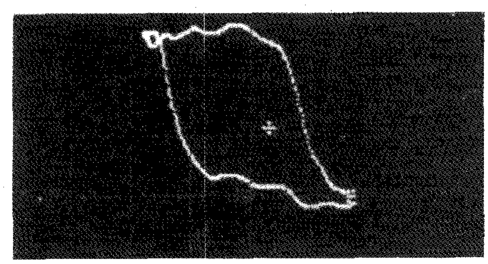
The resistance-field transfer curves $R(H)$ of these samples under exciting field of various strengths were investigated. The switching of the double ferromagnetic layers with different coercivities gives rise to the "double-hump" shaped curve depicted in Fig. 3(a), where the applied field is between ±40 Oe. Fig. 3(b) and (c) illustrate the $R(H)$ response for the same sample operating in the mode in which only the soft component is switched by limiting an applied field between ±20 Oe. In Fig. 3(b) the element is initially saturated by a field of −40 Oe while in Fig. 3(c) initially by +40 Oe. In fact, as can be seen in Fig. 3, a storage mechanism exists: the small-field response's slope is dependent on its past magnetic history. Naturally, the plus or minus slope can be used to produce a polar signal to distinguish the remanent state.



(a) Main loop of magnetoresistance-field response in which the applied field is between ±40 Oe.



(b) Minor loop in which the applied field is between ±40 Oe. The element is initially saturated by −40 Oe.



(c) Minor loop in which the applied field is between ±20 Oe. The element is initially saturated by +40 Oe.

Fig. 3. Storage mechanism of spin tunneling junction.

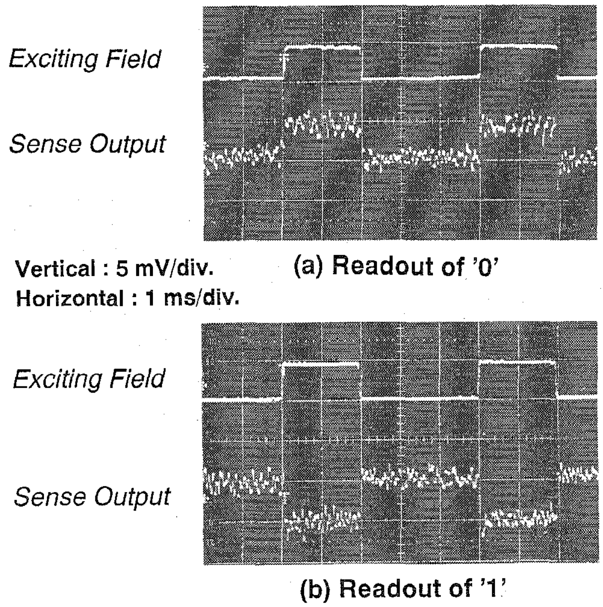


Fig. 4. Response against the square-wave field.

IV. Tests

Data readout is performed by monitoring the resistance against the square-wave exciting field. In order to measure the resistance change, the response voltage is observed by flowing a 10 mA dc current through the junction. In the Al_2O_3 tunneling barrier, the barrier height is of the order 1–3 eV. For this reason, ΔR/R changes little with a small voltage bias, whereas it decreases significantly at higher bias, in qualitative agreement with Moodera's results [3]. As illustrated in the above section, if the + slope corresponds to stored 0, then the − slope corresponds to 1 in minor loops of $R(H)$ responses. Thus, a plus (corresponding to 0) or minus pulse (corresponding to 1) sense voltage across the junction should appear. It proved to be true by the pulse sequence of Fig. 4. A voltage difference between the two cell states of 10 mV range has been realized. Furthermore, the tests indicated that a stable readout state involving 3×10^8 excitations can be achieved. Thus this element is confirmed to have non-destructive readout (NDRO) property. As regards to random access selection, it can be realized by making use of the threshold characteristics [6].

V. Results and Discussions

We succeeded in fabricating a 2×2 bit Spin Tunneling Random Access Memory (STram). The spin tunneling junctions provide an excellent means of storing a binary data in the hard components, and sensing its remanent state by switching the soft component in such a way that the magnetic state of the hard component remains unaltered. This memory is non-volatile, compact and has nondestructive readout properties. Using such junctions as memory elements would realize fast transient response [6] and low-power dissipation. Magnetic materials and devices have been the backbone of storage devices for decades. For the non-volatile memory applications, they are not able to compete against silicon devices due to many of the attributes of the magnetic materials and device characteristics, such as material substrates, process compatibility, lack of address decode logic, small readback signal from cell and large write current, etc. [7]. However, the progress in microstructured spin tunneling junctions lead to the design of a new non-volatile RAM with much needed improvement in the read/write characteristics. For example, we have confirmed that a practical problem in CIP memory [8], [9] that ultra-high density results in low SNR due to serial electrical relationship between cells could be solved by STram, owing to its parallel connections [10] (see Fig. 1). Furthermore, modern advances in electro-chemical techniques [11] make it possible to realize a 1–100 Gb/cm^2 dense arrays of nanometer-sized tunneling junctions.

References

[1] M. Jullier, *Phys. Let.* 54A, 225(1975).
[2] T. Miyazaki, N. Tezuka, *J. Magn. Magn. Mater.* 126,430(1993)
[3] J. S. Moodera, L. R. Kinder, T. M. Wong, R. Meservey, *Phys. Rev. Lett.*, Vol. 74, No. 16, p.3273, 1995
[4] D. J. Monsma, J. C. Lodder, T. J. A. Popm, B. Dieny, *Physical Review Letters*, Vol. 74, No. 26, 5260(1995)
[5] R. Rottmayer, Jian-Gang Zhu, *IEEE Tran. Magn.*, Vol. 31, No. 6, 2597(1995)
[6] J. M. Daughton, P. A. Bade, M. L. Jenson, and M. M. M. Rahmati, *IEEE Trans.*, Mag-28, No.5, (1992)
[7] D. D. Tang, P. K. Wang, V. S. Speriosu, S. Le, AP-03, *Digest of Intermag*, April 16–19, 1995
[8] Z. G. Wang, Y. Nakamura, *IEEE Tran. Magn.*, Vol.32, No.2, 1996
[9] Z. G. Wang, Y. Nakamura, *J. Appl. Phys.*, 79(8), 1996
[10] Z. G. Wang, Y. Nakamura, *J. Mag. Soc. Jpn.*, 19, 108(1995)
[11] K. Liu, K. Nagodawithana, P. C. Searson, C. L. Chien, *Phys. Rev. B*, Vol 51,No.11, 7381(1995)